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Recent Advances in GaN Light Emitting Devices

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SUMMARY

GaN-based light emitting devices including the light emitting diodes (LEDs) and diode lasers have attraction great attention in recent years. Because these devices are capable of generation of short wavelength emissions in UV and blue regions that can have many practical applications such as high-density storage, high-speed data processing, solid state lighting, flat panel color display, and quantum computing. However, the realization of GaN-based lasers is relatively recent in comparison with the GaAs-based lasers. Therefore the technology of GaN based lasers is still in the development stage, and many technical issues remain to be addressed and resolved before those applications can be realized.

Among many technical issues the material and device fabrication related problems are two key concerns. At present the GaN light emitting devices are grown on the foreign substrates mostly sapphire substrate. However due the lattice mismatch and temperature expansion coefficient difference between the sapphire and GaN, the GaN device structures grown sapphire substrate are known to have many defects that tend to effect the device performance. Other factors such as insulating property and non-cleavage of sapphire material make manufacture of GaN light emitting devices difficult. In addition to the substrate material problem, the achievement of high carrier concentration p-type GaN and low specific resistance p-type ohmic contact are two major technical issues in device fabrication. Typical p-type carrier concentrations can be achieved by Mg-doping in MOCVD grown GaN are in the order of few 10^{17} cm^{-3} , which are far below the requirement for light emitting devices especially lasers. The low specific resistance ohmic contact for n-type GaN has been achieved without much difficulty; but for p-type GaN contact low specific resistance ohmic contacts are not easy to obtain because of the high work function and low carrier concentration.

This issue can impact the performance of GaN based light emission device. In the paper we highlight the recent progress in these related technical areas

To investigate the possibility of creating free standing GaN material that can be used for growth of the desired light emitting device structures, we investigated the laser liftoff (LLO) technique to separate the GaN epitaxial layer from the sapphire substrate. A XeF excimer laser at 248-nm emission wavelength is used for LLO process.⁽¹⁾ The schematic of LLO setup is shown in Fig. 1. The laser irradiates from the backside of the sapphire substrate on which a thin epitaxial layer of GaN material was grown. With laser fluence exceeding the critical fluence of 0.3 J-cm^2 the portion of GaN material adjacent to the sapphire interface dissociated into nitrogen gas and Ga causing the separation of GaN from the sapphire substrate. The lift-off freestanding GaN film, which is attached to the supporting Si holder, showed no major crystal quality change from the X-ray measurements. The photoluminescence spectrum of the sample before and after the LLO also showed no shift in the peak emission wavelength as shown in Fig. 2. The LLO process has also been used to create freestanding GaN LED samples originally grown on the sapphire substrate. The lift-off LEDs show the light emission with same wavelength similar to the LED before the LLO. This LLO technique should be feasible for creating GaN substrate for growth of lattice-matched GaN light emitting devices.

In the area of achieving high carrier concentration in p-type GaN material, we employed implantation of low activation energy Be ions into MOCVD grown Mg-doped p-type GaN material that has a low carrier concentration of about $1 \times 10^{17} \text{ cm}^{-3}$. The Mg-doped GaN samples were implanted with Be ions with energy of 50 keV at a dose of 10^{-4} cm^{-2} . After rapid thermal annealing of the implanted samples at 1100°C for 60 sec, the carrier concentration of the annealed GaN samples exhibited higher carrier concentrations ranging from $3 \times 10^{18} \text{ cm}^{-3}$ to $8 \times 10^{19} \text{ cm}^{-3}$.⁽²⁾ From the measured temperature dependence of the photoluminescence spectrum we found an estimated reduction of the Mg activation energy of about 30 % as the result of Be implantation. This could be partially responsible for the enhancement in the carrier concentration of the implanted Mg-doped p-type GaN. This result suggests that Be ion implantation may be a feasible way of obtaining high carrier concentration in p-type GaN material.

A new type of metallization scheme was developed for p-type GaN contact based on Au-Pd-Ni alloy. The metal contact layer structure composed of 20 nm Ni, 20 nm Pd, and 100 nm Au and

was deposited in sequence on two types of p-type GaN samples grown by MOCVD. One is the as-grown GaN samples with low carrier concentration of about $4 \times 10^{17} \text{ cm}^{-3}$. Another is the Be-implanted samples with high carrier concentration of about $8 \times 10^{19} \text{ cm}^{-3}$. The specific contact resistance measured by circular transmission line method showed low concentration samples have good ohmic contact with a specific contact resistance of about $1 \times 10^{-4} \Omega \text{ cm}^2$ after annealed the contact at 550°C in the oxygen atmosphere. The high carrier concentration samples showed ohmic contact with specific contact resistance as low as $4.5 \times 10^{-6} \Omega \text{ cm}^2$ without any annealing as shown in Fig. 3.^(3,4)

In summary we have demonstrated the creation of free standing GaN material and LED devices using the laser lift-off technique that made the fabrication of GaN light emitting devices on lattice-matched substrate feasible. By implantation of low activation energy Be ions into Mg-doped GaN samples and annealed properly the carrier concentration as high as $8 \times 10^{19} \text{ cm}^{-3}$ was obtained. We also developed new metallization scheme using Ni/Pd/Au alloy for p-type GaN and achieved good ohmic contacts with specific contact resistance of $1 \times 10^{-4} \Omega \text{ cm}^2$ for low carrier concentration samples and $4.5 \times 10^{-6} \Omega \text{ cm}^2$ for high carrier concentration samples.

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References:

1. C. F. Chu, C. K. Lee, C. C. Yu, Y. K. Tsai, C. R. Yang, and S. C. Wang: Materials Science & Engineering B82 (2001) 42.
2. C. C. Yu, C. F. Chu, J. Y. Tsai, C. F. Lin, W. H. Lan, C. I. Chiang and S. C. Wang: Jpn. J. Appl. Phys. Vol. 40(2001) L417.
3. C. F. Chu, C. C. Yu, Y. K. Wang, J. Y. Tsai, F. I. Lai, and S. C. Wang: Appl. Phys. Lett. Vol. 77, No. 21, 3423.
4. S. C. Wang, C. F. Chu, C. C. Yu, Y. K. Wang and F. I. Lai: Electrochemical Soc. Proc. 2001-1, 139.

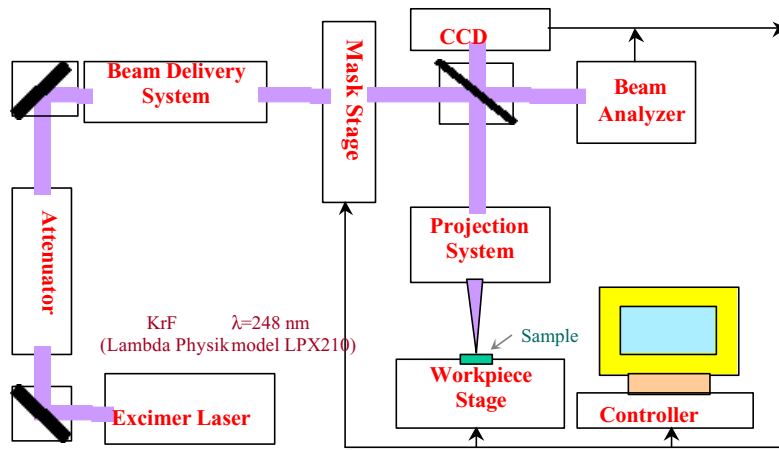


Fig. 1 Experimental setup for laser lift-off

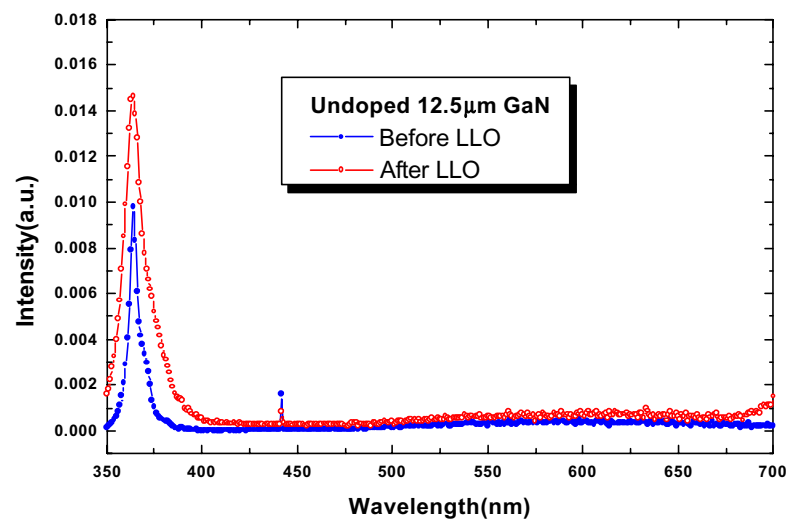


Fig. 2 Photoluminescence spectrum of GaN material before and after laser lift-off

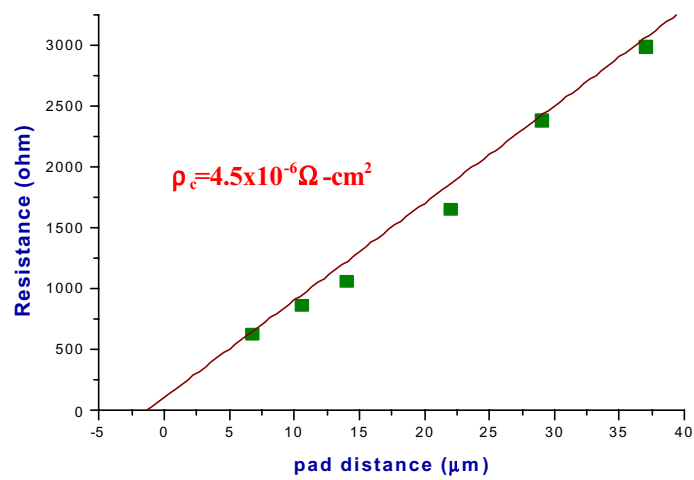


Fig. 3 Specific resistance measured by the CTLM for different pad distances